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CROP PRODUCTION

Postharvest quality of yellow passion fruit grown using espalier and trellis systems in an annual growth cycle

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ABSTRACT. Yellow passion fruit (*Passiflora edulis*) is a vine plant whose pulp is mainly used for juice production. Brazil accounts for approximately 90% of global passion fruit production, while Europe is an emerging market. Passion fruit cultivation requires support structures, typically oriented vertically using the espalier system or horizontally using the trellis system, constituting up to 70% of production costs. Despite its native origin, there is limited research on the impact of cultivation systems on fruit quality. This study compares trellis systems with two wires to the espalier system across two growing seasons under annual cultivation. Fruits were harvested when at least two-thirds of the skin turned yellow. Rainfall accumulation and light availability within each system were measured. Various fruit characteristics-including skin color, skin thickness, fruit mass, longitudinal and transverse diameters, pulp mass, pulp yield with seeds, total soluble solids, titratable acidity, and ascorbic acid content—were evaluated in both systems across both seasons. Results indicate that the trellis system consistently produced higher pulp mass and larger fruit diameter across seasons. No significant differences were found in postharvest quality between the systems. Based on these findings, the trellis system is recommended for annual yellow passion fruit cultivation.

Keywords: *Passiflora edulis*; postharvest; pulp mass; fruit diameter.

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Introduction

Passiflora edulis, commonly known as passion fruit, is a perennial vine in the Passifloraceae family, comprising 18 genera and 530 species (Ghada et al., 2020). Globally, passion fruit cultivation primarily involves two types: purple passion fruit (*Passiflora edulis* Sims) and yellow passion fruit (*Passiflora edulis* Sims) (Shahidah et al., 2021b). Both varieties are morphologically similar, with round shape, leathery skin, and aromatic, juicy pulp containing small black seeds (Md Nor et al., 2022). However, they differ in growth performance and fruit characteristics. The yellow passion fruit, noted for its vigorous vine, lacks chilling resistance and produces more acidic juice, making it particularly valuable in the food processing industry (Md Nor & Ding, 2021a). Globally, yellow passion fruit is primarily cultivated in South America (Kishore et al., 2006).

Worldwide, passion fruit production is approximately 1.5 million tons (Asande et al., 2023). Europe represents the largest market, surpassing South and North America (Md Nor et al., 2022). In early 2020, the COVID-19 pandemic significantly influenced consumer behavior, leading to an increased emphasis on healthier diets, with a focus on fruits and vegetables (Borsellino et al., 2020; Md Nor et al., 2022). Market analysts predict a continued increase in demand for passion fruit puree through 2027, largely driven by the pandemic's impact (The Insight Partners, 2020). Rising global passion fruit prices present a lucrative opportunity, especially for producers in tropical and subtropical regions. Brazil leads global production, accounting for approximately 90% of total output, supporting both fresh consumption and pulp concentrate for domestic and international juice markets (Asande et al., 2023; Instituto Brasileiro de Geografia e Estatística [IBGE], 2021; Nascimento et al., 2012). This production is an essential income source for small-scale farmers, playing a significant role in sustaining family agriculture (Araújo Neto et al., 2005).

In 2010, passion fruit cultivation faced challenges, including a 33% reduction in cultivated area, a 45% drop in production, and a 17% decrease in productivity, due to pests, diseases such as Cowpea aphid-borne mosaic virus (CABMV), scarcity of disease-free planting materials (Wangungu et al., 2010; Horticultural Crops Development Authority [HCDA], 2020), and pollination issues (Oliveira & Frizzas, 2014). This decline continued in various Brazilian regions in subsequent years (IBGE, 2021; Landau & Silva, 2020). In the 2020/2021 agricultural season, Brazil's passion fruit growing area was 44,827 hectares, yielding 15.25 tons per hectare, totaling 683,993 tons of production (IBGE, 2021).

Passion fruit is a vigorous climbing vine with a rapid growth rate. It begins fruiting within six months of transplantation, and its productive lifespan lasts up to two years (Md Nor & Ding, 2019). Morphologically, the fruit's tissues are divided into the pericarp (peel) and endocarp (seeds and juice) (Md Nor et al., 2022).

Given its climbing nature, support structures are crucial for passion fruit cultivation. These structures represent up to 70% of total production costs (Cleves-Leguízamo, 2021). Typically, the espalier system, involving vertical wire orientation, or the trellis system, involving horizontal wire structures, are used for plant support (Pedro Júnior et al., 2007). The espalier system consists of one to three vertically arranged wires, which is the most common in Brazil due to its suitability for mechanical treatments and lower implementation costs (Monzani et al., 2018). The trellis system, in contrast, features horizontal intertwined wire arrangements (from 0.7 to 1.0 m) that form a support net at a height of approximately 2.1 meters (Miranda, 2009). Studies have shown no differences in leaf severity of diseases like anthracnose, cladosporiosis, bacterial spot, and woodiness (CABMV) between trellis and espalier systems (Monzani et al., 2018). However, information on the impact of these systems on postharvest fruit quality in Brazil is lacking.

Recognizing the importance of selecting the optimal cultivation system, this study aims to compare espalier and trellis plant conduction methods, focusing specifically on their influence on fruit quality.

Material and methods

Field experiment

The study was conducted in a passion fruit orchard located in Araquari, Santa Catarina State, Brazil (21°42'49" S, 41°20'33" W, 8 m above sea level). The research spanned two consecutive cycles: the first from August 2013 to June 2014 (2013/2014 season), and the second from August 2014 to June 2015 (2014/2015 season). The experiment was conducted in an orchard managed under two systems: an espalier with two wires and a trellis system. The study utilized a randomized block design with two treatments (two plant conduction systems) and eight replications. Each plot contained five functional plants and two border plants, with spacing of 2.3 m between rows, 2.0 m between plants, and 6.0 m between posts. Transplanting pits measured 0.40 × 0.40 × 0.40 m. The espalier system featured two wires fixed at 1.4 m and 2.1 m above ground level, while the trellis system included wires interwoven horizontally at 0.70 m intervals, longitudinally and transversely, at a height of 2.1 m (Figure 1). Monzani et al. (2018) provided detailed descriptions of the orchard's features and the practices employed in the area.

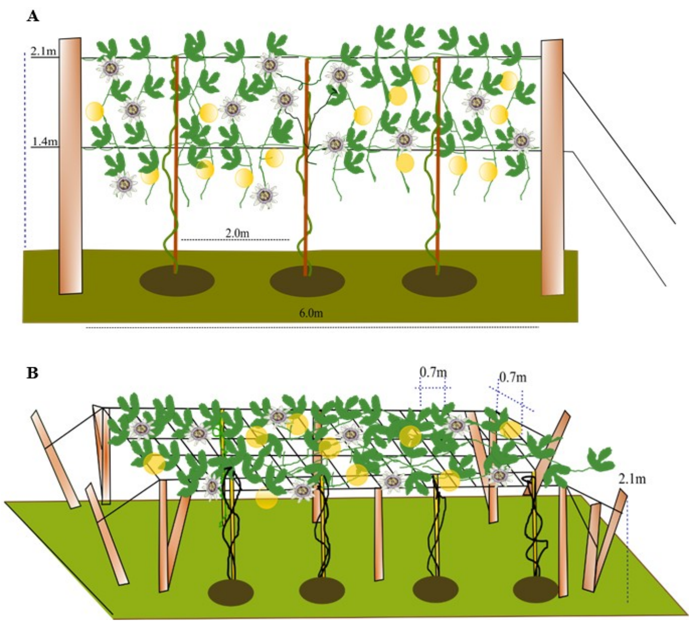

Figure 1. A) Espalier training system for passion fruit. The espalier system consists of two wires positioned at 1.4 and 2.1 m above the ground. B) Trellis training system for passion fruit. The trellis system features wires intertwined horizontally at 0.70 m intervals, both longitudinally and transversely, at a height of 2.1 m. In both training systems, plants were spaced 2.3 m between rows, 2.0 m between individual plants, and 6.0 m between posts.

To evaluate rainfall accumulation on the fruit in each system, a 50 mL graduated Falcon tube was placed adjacent to the fruit stalks. These tubes remained in the orchard from April 15 to April 25, 2015, during which total precipitation was 150 mm. In the espalier system, tubes were placed at a height of 1.50 m above ground, while in the trellis system, they were positioned at 2.00 m. After this period, the tubes were collected, and the volume of accumulated water was measured.

Light intensity within the different plant conduction systems was measured using an ICEL® LD-550 lux meter. The sensor was positioned near each plant at 9:00 am, 12:00 pm, and 3:00 pm over three consecutive days (April 13 to April 15, 2015). Measurements were taken at 1.50 m and 2.00 m heights in the espalier and trellis systems, respectively.

Fruit quality assessment

Fruits were harvested systematically every two weeks from December to July during both growing seasons for each training system. Selection criteria for harvesting were applied uniformly, requiring that at least two-thirds of the fruit skin exhibit yellow coloration. During each harvest, fruits from each plant were counted, weighed, and measured for transverse and longitudinal diameters using a digital caliper. These measurements were essential for determining the correlation between fruit diameters and their morphological attributes.

Subsequently, fruits were sectioned transversely and separated into pulp with seeds and skin components to measure pulp mass, skin mass, and skin thickness. Skin thickness was measured at three randomly selected points using a digital caliper for precision. Pulp yield was calculated as the ratio of pulp mass per fruit to total fruit mass, expressed as a percentage.

Fruit quality assessments for both training systems over the two growing seasons were performed on pulp extracted from 20 fruits per system in each of the eight replications. Fruit collection took place at three-day intervals during the first half of April each year, with only fruits weighing over 190 g and having diameters greater than 5 cm selected. Skin color was quantified using a colorimeter, yielding L (brightness) values around 72.09, a (red/green content) values of approximately -7.55, and b (yellow/blue content) values around 55.14. Fruits were grouped into samples of four units per plot, placed in sealed plastic containers, and frozen for subsequent quality analysis.

Total soluble solids content was determined using an Instrutherm® portable refractometer (°Brix). The pH was measured using a Phtek® digital benchtop pH meter, by direct immersion of the electrode in the juice. Total titratable acidity (expressed as % citric acid) was calculated using the following formula:

$$\text{Citric acid (\%)} = (Vg * N * f * Eq.\ Ac.) / 10 * g$$

where: *Vg* is the volume of NaOH used (in mL); *N* is the normality of the NaOH solution (0.1 N); *f* is the correction factor for NaOH standardization (1.00Eq. Ac. is the equivalent weight of citric acid (64 for passion fruit); and *g* is the sample mass (Ministério da Agricultura, Pecuária e Abastecimento [MAPA], 2021).

The ascorbic acid (AA) content of the pulp was determined using a modified Tillmans method, based on a redox reaction. The oxidizing agent was 2,6-dichloroindophenol, with 1% oxalic acid solution used as a stabilizer. A 10 mL aliquot of the ascorbic acid standard solution, containing 50 mL of 1% oxalic acid solution, was pipetted into a 100 mL Erlenmeyer flask and titrated with a 2% 2,6-dichlorophenolindophenol-sodium solution until a persistent pink color was observed for 15 seconds. Results were expressed in mg of ascorbic acid per 100 g of juice, as recommended by MAPA (2013).

Data analysis

Data on water collection, light intensity, and fruit quality were assessed for normality of experimental error using the Kolmogorov-Smirnov test and for homogeneity of variance using the Bartlett test, both at a 5% probability level. Once these assumptions were validated, an analysis of variance (ANOVA) was performed using the F-test at a 5% significance level ($p > 0.05$), employing ASSISTAT 7.7 beta software (Silva & Azevedo, 2016).

Results

The trellis training system demonstrated superior fruit mass, pulp mass, and transverse (equatorial) diameter (TD) compared to the espalier system. These results align with the higher productivity observed by Monzani et al. (2018) in trellis systems. Specifically, pulp mass was 6.61% higher in the trellis system during the second season, while no significant differences were observed in the first season. Other measured attributes, such as skin mass, longitudinal diameter (LD), and the ratio of longitudinal diameter to skin thickness, showed no significant differences between the two training systems across both growing seasons (Table 1).

Table 1. Physical characteristics of passion fruit grown using espalier and trellis production systems during the first and second growing seasons.

Feature	1st growing season		2nd growing season	
	Espalier	Trellis	Espalier	Trellis
Fruit mass (g)	196.4 b	221.8 a	238.9 b	263.3 a
Pulp mass (g)	107.1 b	120.9 a	110.0 b	129.2 a
Skin mass (g)	101.1 ns	108.8	133.1 ns	140.1
Pulp yield with seeds (%)	54.6 ns	54.6	46.0 b	49.0 a
Longitudinal diameter (LD) (cm)	8.9 ns	9.3	9.6 ns	9.8
Transverse diameter (TD) (cm)	7.6 b	7.9 a	8.3 b	8.6 a
LD/TD ratio	1.2 ns	1.1	1.1 ns	1.1
Skin thickness (cm)	0.9 ns	0.9	1.0 ns	0.9

*Means followed by the same lowercase letters within rows do not differ from each other by the F test in each growing season. ns non-significant ($p \geq 0.05$).

Regarding the postharvest characteristics of the pulp in the espalier and trellis systems, no significant differences were found between the two systems in either growing season for all analyzed features, including total soluble solids content (TSS), total titratable acidity (TTA), TSS/TTA ratio, pH, and ascorbic acid content (Table 2).

Table 2. Total soluble solids content (TSS), total titratable acidity (TTA), TSS/TTA ratio, pH, ascorbic acid levels, collected water, light intensity, and solar injuries in passion fruits grown using espalier and trellis systems during the first and second growing seasons.

Feature	1st growing season		2nd growing season	
	Espalier	Trellis	Espalier	Trellis
Total soluble solids (ºBrix)	12.5 ns	12.2	12.2 ns	12.2
Total titratable acidity (%)	4.0 ns	3.8	4.2 ns	4.0
TSS/TTA ratio	3.0 ns	3.0	2.8 ns	2.8
pH	3.3 ns	3.2	3.0 ns	3.1
Ascorbic Acid (mg 100 g^{-1})	26.9 ns	26.3	25.3 ns	26.9
Collected water (mL)	na	na	12.9 b	16.9 a
Luminosity (1000Lux)	na	na	15.6 a	3.3 b
Solar injuries	2.8 ns	4.2	11.8 a	5.5 b

ns non-significant by the F-test ($p \geq 0.05$). na: non-accessed.

Solar injuries in fruits showed no significant differences between the espalier and trellis systems during the first growing season. However, in the second season, solar injuries were higher in the espalier system compared to the trellis system, which was attributed to the fact that luminosity was approximately five times greater in the espalier system (Table 2).

Discussion

The trellis system showed several advantages, notably increasing fruit mass, pulp content, and transverse diameter. Although no differences in postharvest quality were observed between the trellis and espalier systems, the trellis system resulted in fruits that experienced increased water exposure while being protected from solar injuries due to reduced sun exposure. These findings provide valuable insights for growers in choosing an optimal training system.

Production and quality of sour passion fruit are critical for both fresh consumption and industrial processing. For fresh markets, it is recommended that the fruit have a total titratable acidity (TTA) of 3.2-4.5%, juice yield above 40%, ascorbic acid content between 13 and 20 mg per 100 g, and fruit mass above 120 g, with high-demand markets favoring fruits without blemishes (Barros et al., 2018). To better classify and determine the fruit's destination, the Technical Regulation for Standards of Identity and Quality (PIQ) from the Ministry of Agriculture, Livestock, and Supply (MAPA, 2021) for sour passion fruit pulp specifies a minimum value of 11 °Brix, total acidity of 2.50% in citric acid, and a pH range of 2.70 to 3.80.

The assessment of ascorbic acid (vitamin C) in passion fruit juice is particularly significant, as it is a key determinant of the juice's nutritional value. The vitamin C content found in this study aligns with existing literature and adheres to quality standards, ranging from 26.1 to 26.6 mg per 100 g of juice for trellis and espalier systems, respectively. Similarly, both fruit mass and soluble solids exceeded quality thresholds, with an average fruit mass of 217.6 g for espalier and 242.5 g for trellis, and soluble solids of 12.3 °Brix for espalier and 12.2 °Brix for trellis. The increase in pulp content observed is particularly relevant for the juice industry, as higher pulp content is typically associated with richer flavor and nutritional value, enhancing the quality of the final product (Silva & Abud, 2017). Additionally, increased fruit mass leads to higher juice yield, positively impacting industrial efficiency and productivity.

The higher water content observed in the trellis system can be attributed to the horizontal configuration of the plants, which facilitates the capture of a substantial amount of water. This water superficially traverses the plant, including the fruits, before reaching the soil, enhancing resilience during dry periods. Adequate water availability has been associated with prolonged crop longevity, improved growth and development, and increased productivity and quality (Sousa et al., 2006).

Additionally, our observations confirmed that fruits grown in the espalier system receive higher light exposure. Fruits exposed to full sunlight tend to be smaller but have higher juice percentage, ascorbic acid content, and soluble solids, and thinner skin (Cleves-Leguízamo, 2021). However, in this study, postharvest attributes such as ascorbic acid content and soluble solids did not differ significantly between the training systems. In the trellis system, fruits are positioned beneath the vegetative canopy, benefiting from increased luminosity while avoiding direct sunlight, which prevents solar injuries. Furthermore, leaves in the trellis system are well exposed to sunlight, which positively affects flowering, pollination, fertilization, fruiting, and productivity by increasing the photosynthetic rate, as noted by Cavichioli et al. (2006). During the second harvest, the incidence of anthracnose in fruits was 22.3% in the espalier system and 10.8% in the trellis system, with significant differences between the systems (data not shown). Anthracnose was observed in all fruits with sun injuries, suggesting a correlation between sun damage and increased disease susceptibility. The greater incidence of sun damage in the espalier system may predispose fruits to anthracnose.

In conclusion, the trellis support system offers significant advantages for sour passion fruit cultivation. This study highlights the importance of selecting an appropriate training system, and the trellis system proves to be an advantageous option for producers.

Conclusion

The trellis training system showed superiority in fruit mass, pulp mass, and transverse diameter compared to the espalier system. The incidence of solar injuries was similar between the systems during the first season but was lower in the trellis system during the second season. The amount of water collected on fruits grown in the trellis system was 17.37% higher, while the luminosity on fruits grown in the espalier system was approximately five times greater, leading to increased exposure to solar radiation.

Data availability

The data are available and interested parties should request them from the corresponding author.

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